A Modeling Study of Aerosol Effects on the Water Vapor near the Tropopause

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Introduction

- Using Aura MLS CO as an aerosol pollution index to classify upper tropospheric clouds as "polluted" or "clean", we found that polluted clouds are associated with higher TTL temperature and water vapor than clean clouds, especially over South-East Asia (*Su et al., J. Climate, 2011*). Thus, pollution over Asia may have a significant impact on stratospheric water vapor, ozone chemistry and global radiative balance.
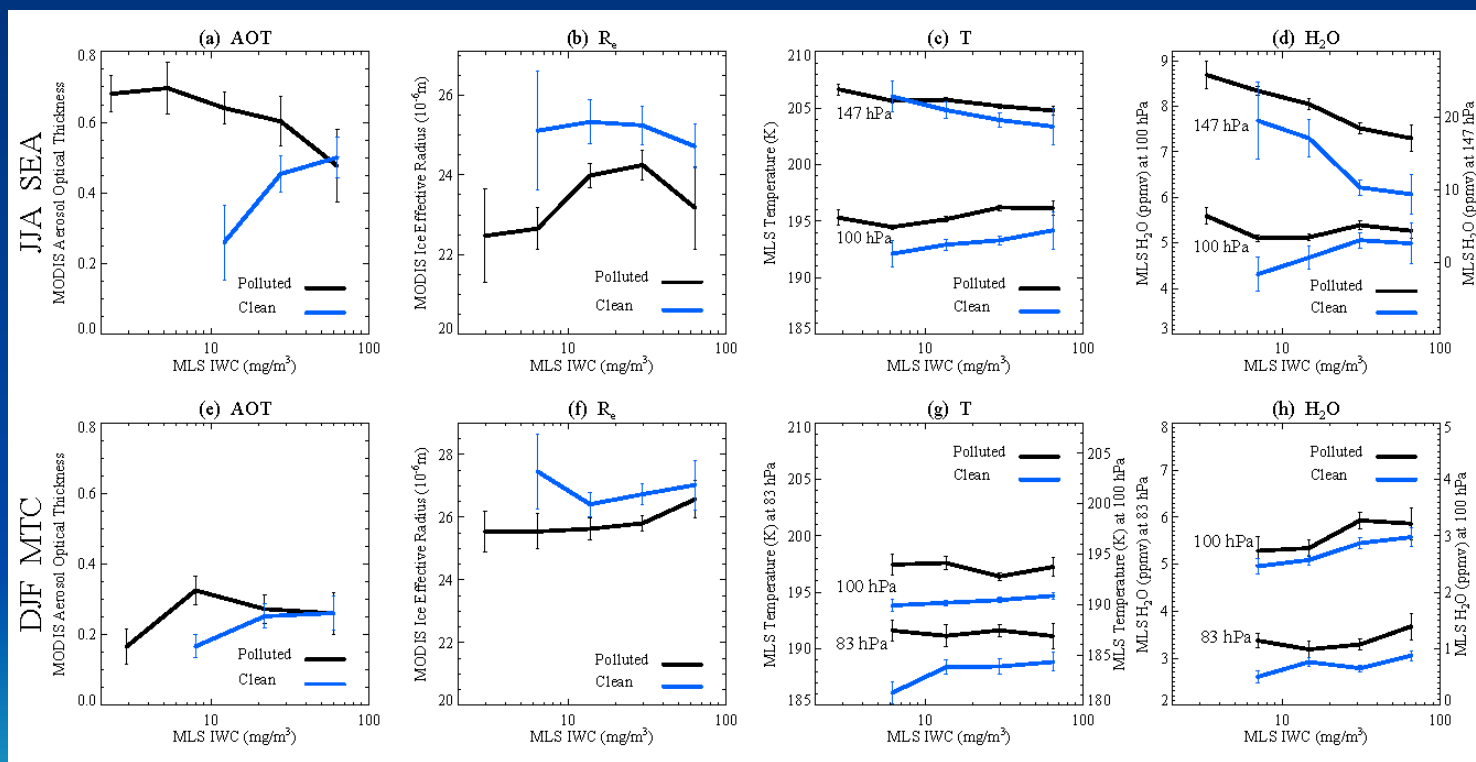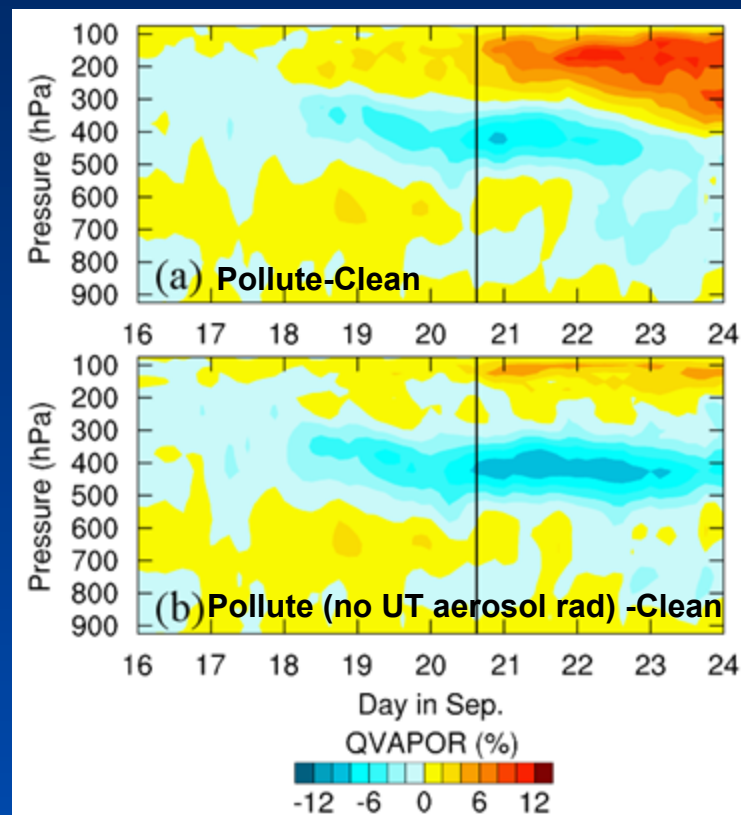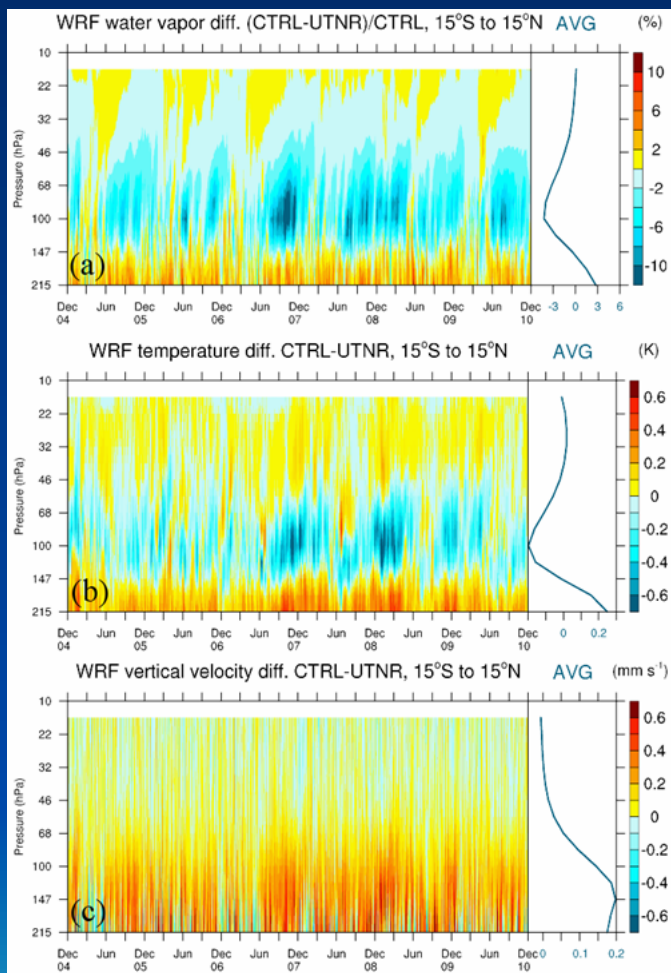

Su et al., J. Clim, 2011

Possible Mechanisms
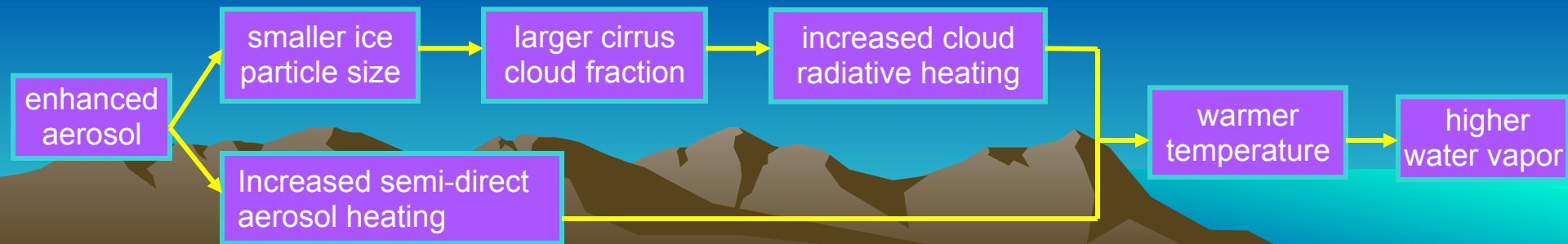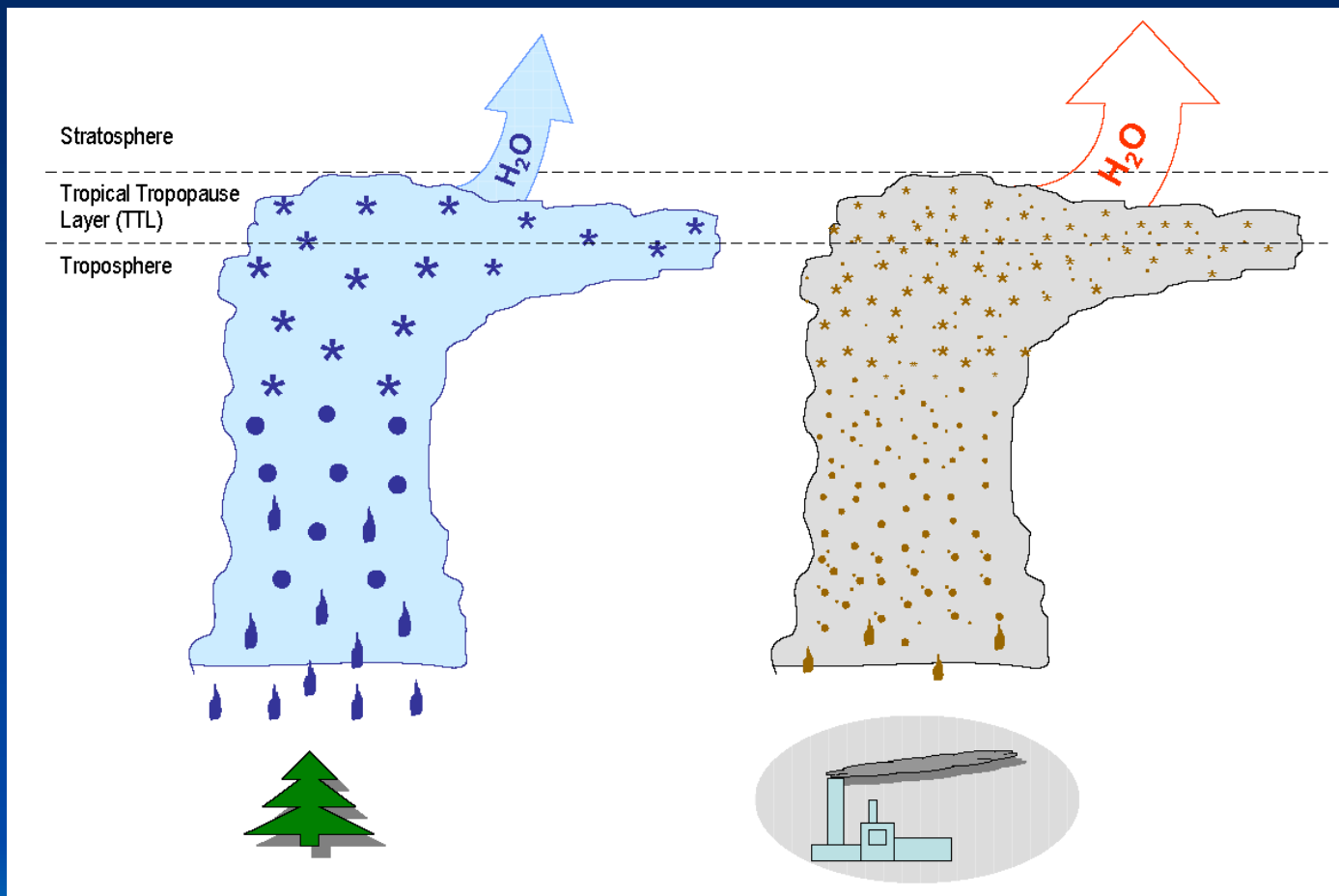
WRF and WRF-Chem Simulations

Wu, L., H. Su and J. H. Jiang: *Hydration or dehydration: competing effects of cloud radiation on the TTL water vapor (poster).*

Wu, L., H. Su, and J. H. Jiang (2011), *Regional simulations of deep convection and biomass burning over South America. Part II: Biomass burning aerosol effects on clouds and precipitation, J. Geophys. Res.*, in press.

Analysis with NCAR CAM5 (the CMIP5 Version)

- 2.5° (lon) x 2° (lat) grids, 30 vertical levels (8 levels from 230-70 hPa)

- Improved two-moment ice cloud microphysics (*Gettelman et al.*, 2010)

- Modal-based aerosol scheme (*Liu et al.*, 2011)

- Homogeneous ice nucleation on sulfate and heterogeneous ice nucleation on dust

- Three runs from 5-year climatological simulations
  Present-day (PD):   Year 2000 IPCC AR5 emission scenario
  Pre-industrial (PI): Year 1850 IPCC AR5 emission scenario
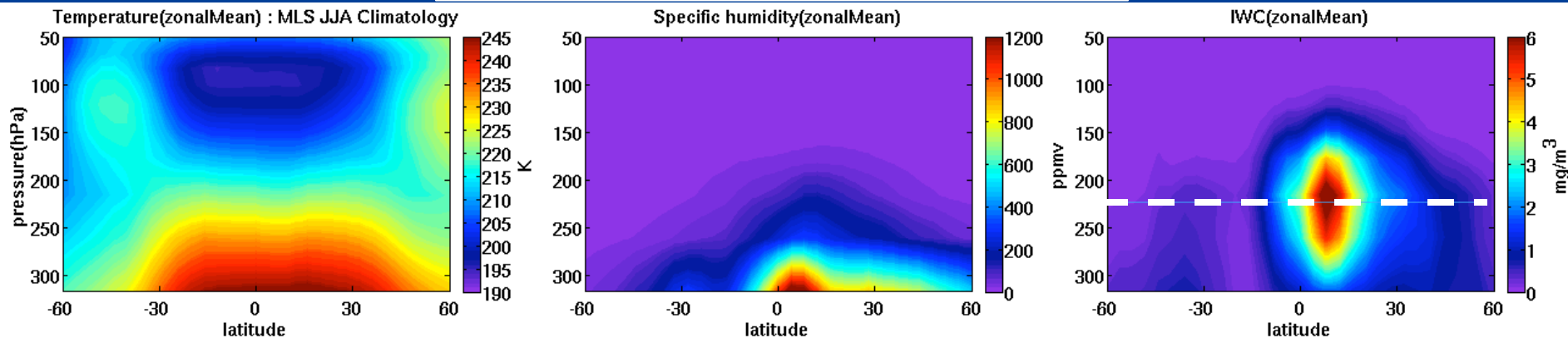 PD nobc run: Black Carbon (BC) radiative effect is turned off

Comparison of Zonal-Means with Aura MLS

CAM5 JJA Climatology
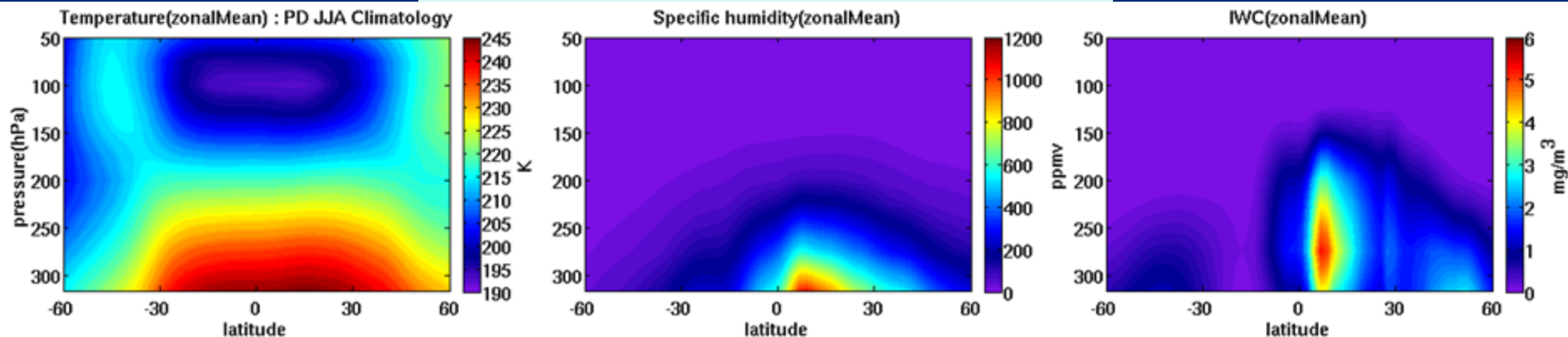
MLS JJA Climatology
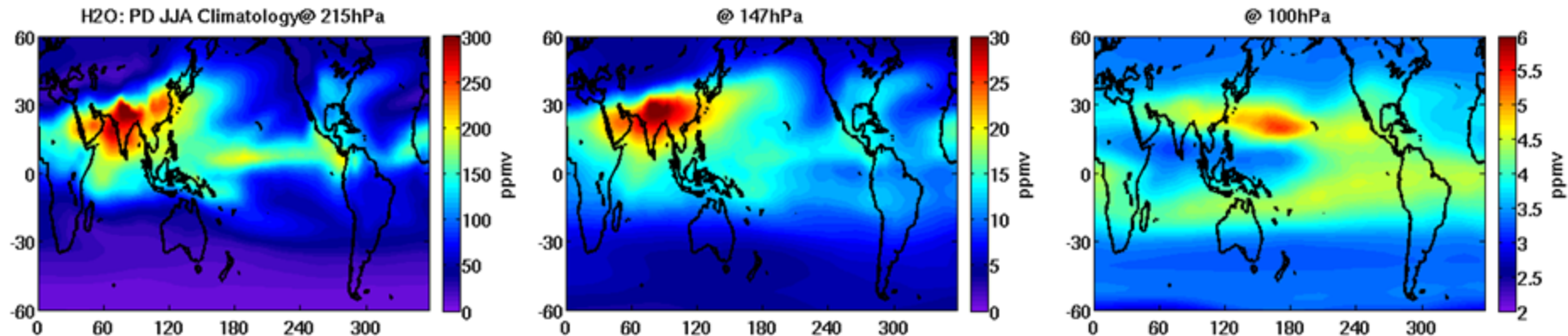
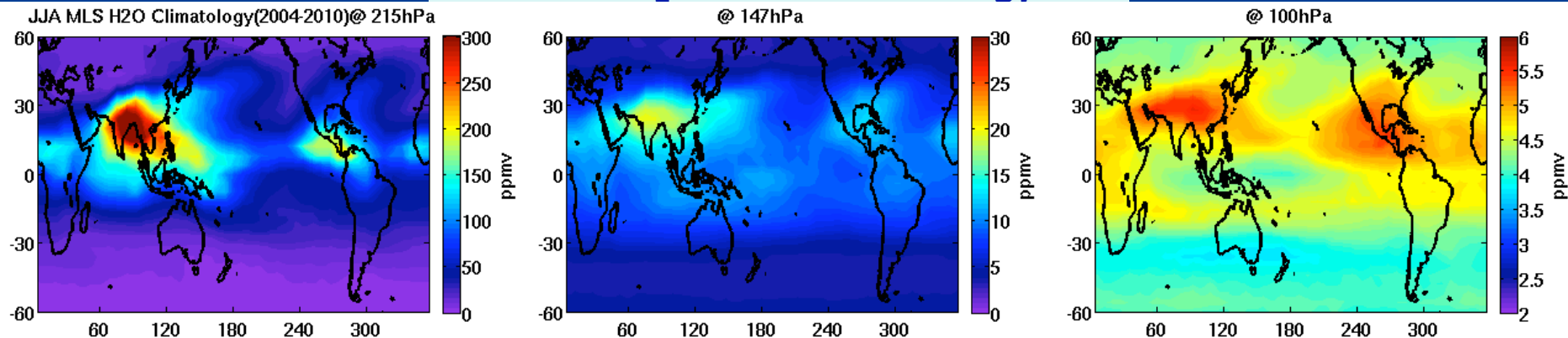- CAM5 (the PD run) simulates well the UTLS regions. The magnitudes of H_2O and IWC are smaller than the observed.

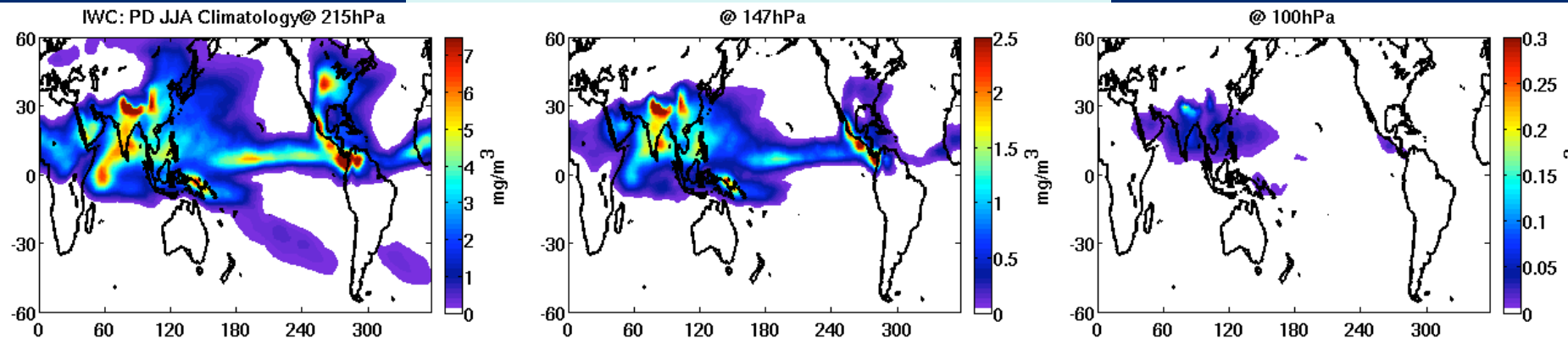# Comparison of H₂O with Aura MLS

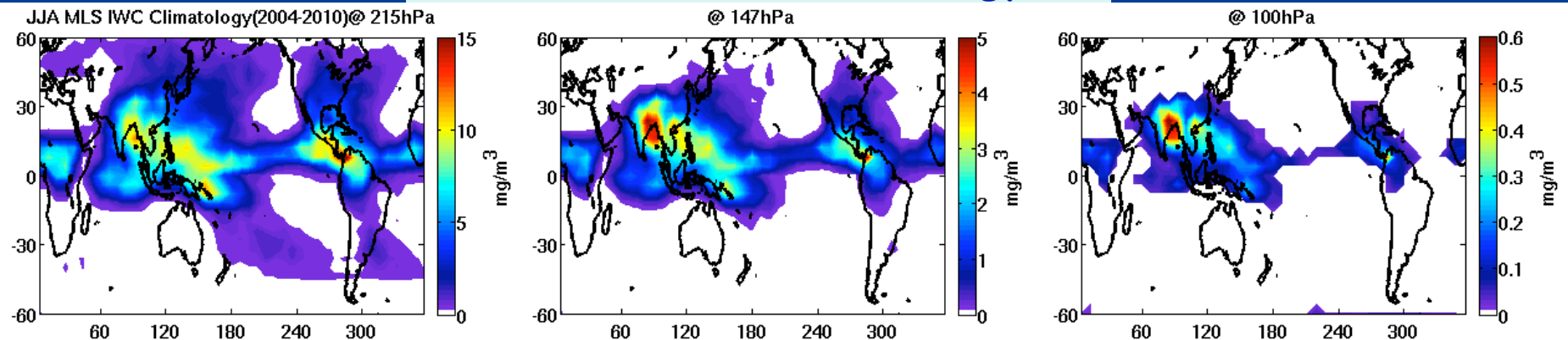## CAM5 H₂O JJA Climatology

MLS H₂O JJA Climatology

- The simulated H₂O at 215 hPa is similar to the observation. The model is biased wet at 147 hPa but dry at 100 hPa.

Comparison of IWC with Aura MLS
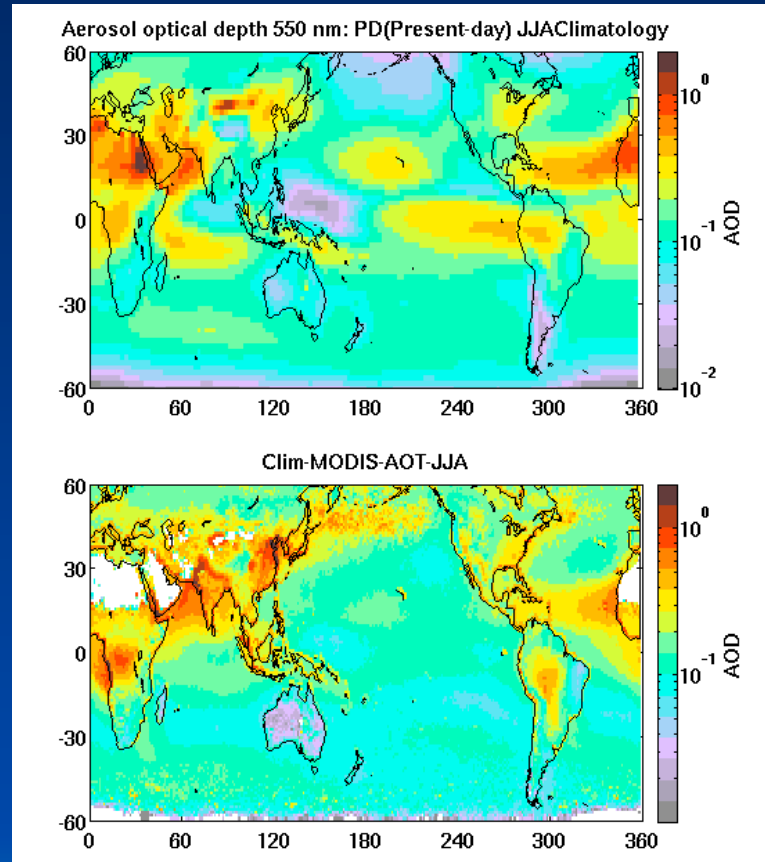
CAM5 IWC JJA Climatology

MLS IWC JJA Climatology

- The spatial distributions of ice clouds are fairly good, but their magnitudes are only half of the observed.
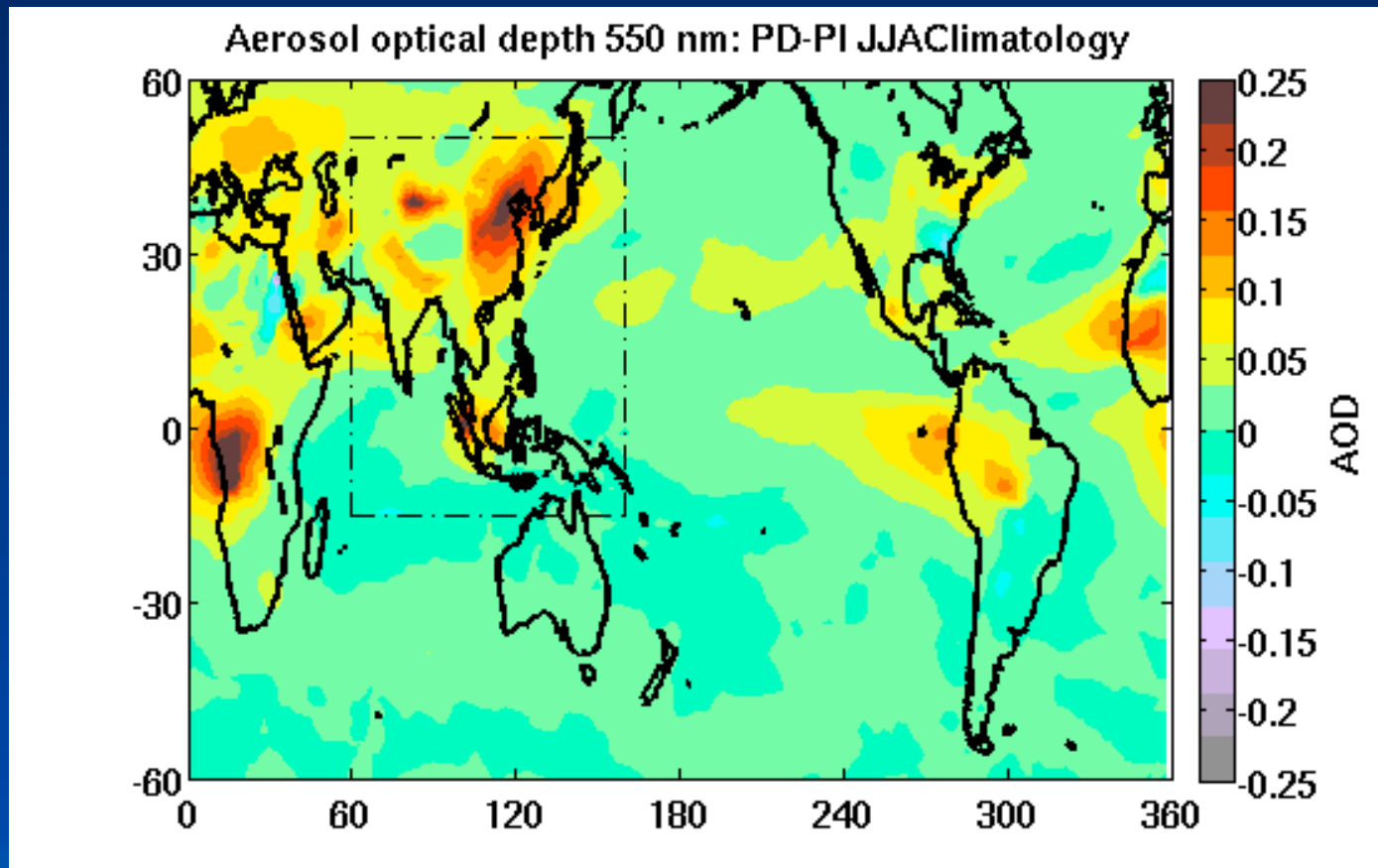
Comparison of Aerosol with Aqua MODIS

Aerosol optical depth 550 nm: PD(Present-day) JJAClimatology

Clim-MODIS-AOT-JJA

- CAM5 approximately reproduces the high aerosol regions, but the aerosol concentration differs from MODIS observation noticeably.

The Difference Between the PD and PI runs

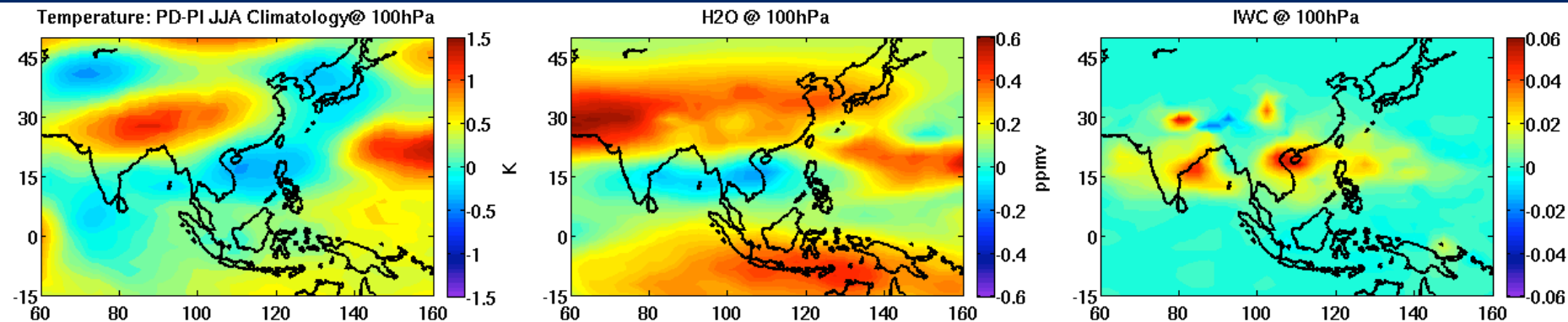Aerosol optical depth 550 nm: PD-PI JJAClimatology

- The South-East Asia shows substantial increase (more than double) of AOD from pre-industrial to present-day conditions.
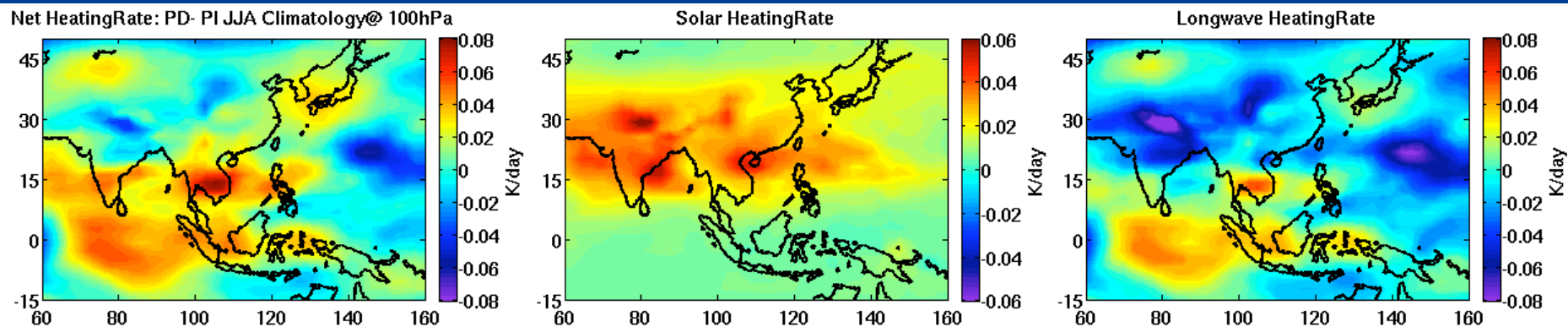
Changes in the UTLS from PI to PD
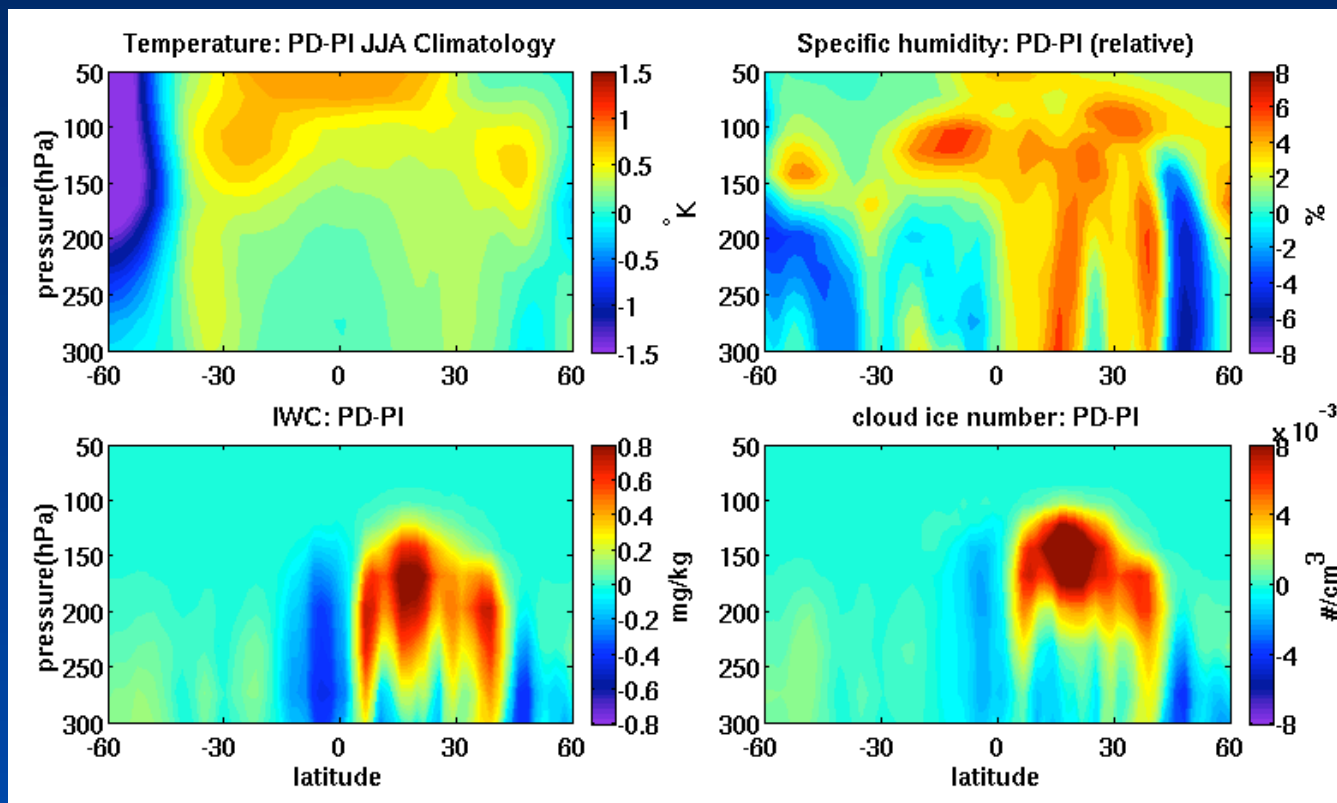
- With increasing aerosols, the tropical UT/LS show higher temperature and water vapor. The mass and number of ice clouds also increase.
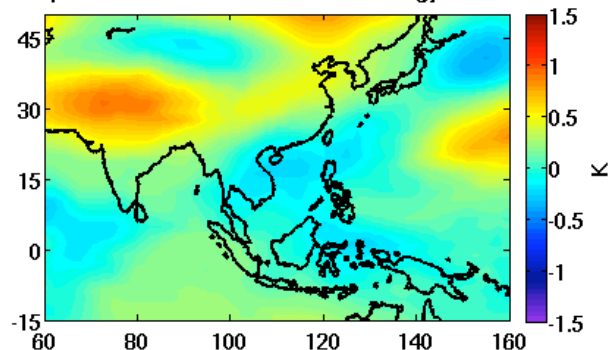
- Increasing aerosols produce higher temperature, H_2O, and cloud ice at 100 hPa.
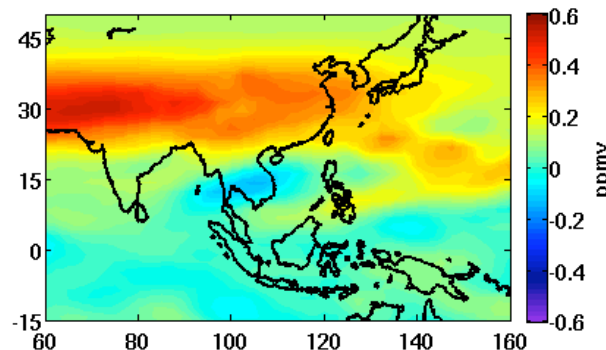
- Radiative heating (primarily solar heating) may be the trigger of the increased temperature and thus water vapor.

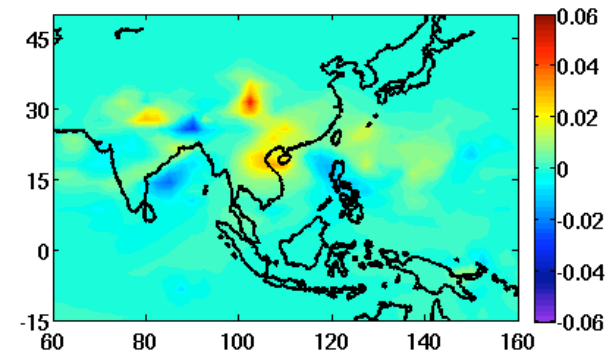# The Radiative Heating of Black Carbon
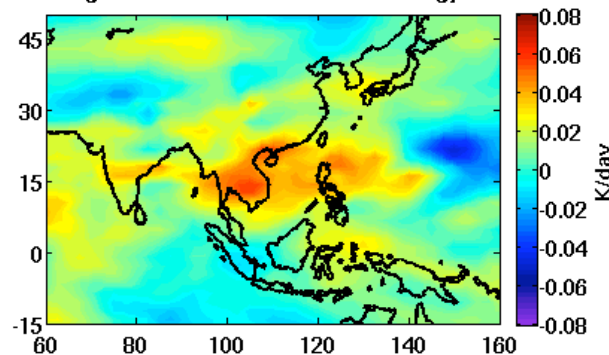## (PD – PDnobc)
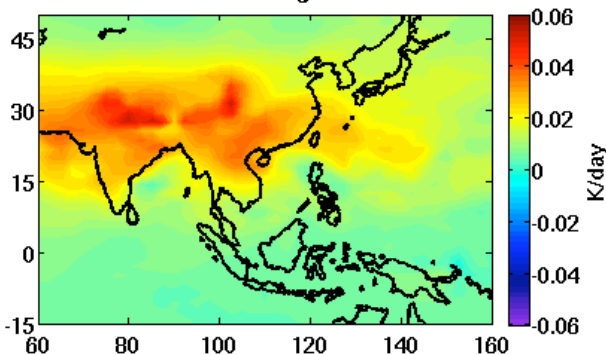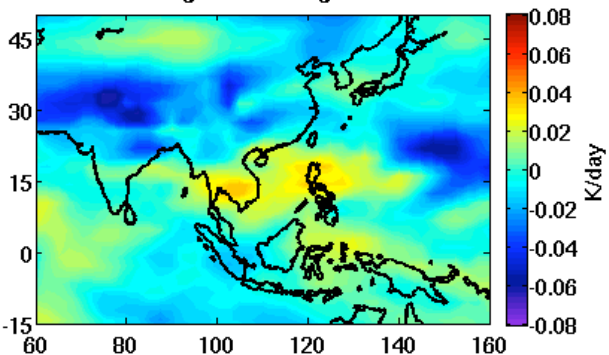
• The PD-PDnobc approximately resembles PD-PI, suggesting that the radiative effect of black carbon makes a dominant contribution to the net aerosol effects.

Averages over South-East Asia
(25°-45°N, 100°-130°E)

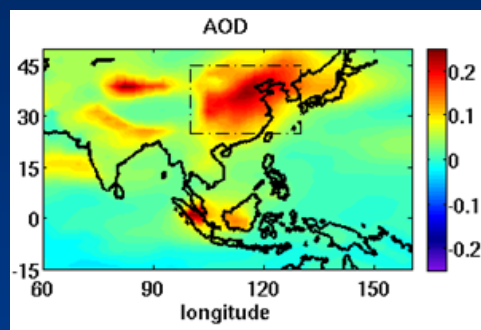|	PD	PD-PI	PD-PDnobc
T_100 (K)	202	0.299	0.292
H_2O_100 (ppmv)	3.96	0.294 (7% of PD)	0.285 (96% of PD-PI)
Q_{rad}_100 (K/day)	0.23	0.009 (4% of PD)	0.012 (133% of PD-PI)
T_147 (K)	210	0.485	0.562
H_2O_147 (ppmv)	16.9	0.728 (4% of PD)	1.524 (209% of PD-PI)
Q_{rad}_147 (K/day)	-0.22	0.023 (10% of PD)	0.014 (61% of PD-PI)
T_215 (K)	225	0.396	0.598
H_2O_215 (ppmv)	171.7	4.897 (3% of PD)	12.98 (265% of PD-PI)
Q_{rad}_215 (K/day)	-1.05	0.116 (11% of PD)	0.034 (29% of PD-PI)

- At 100 hPa, BC's radiative heating contributes primarily to the increase of H_2O.
- At 147 and 215 hPa, other processes (cloud radiation, deep convection, adiabatic cooling, etc) counteract the increase of H_2O by BC radiative heating.
- For TTL water vapor, the direct effect of absorbing aerosols is dominant over the indirect effect of aerosols on clouds.

Conclusions

- The NCAR CAM5 model produces reasonable UTLS simulations and is thus used to investigate the effects of aerosol on the TTL water vapor.

- The increase of aerosols causes higher UTLS temperature and water vapor, along with increasing ice cloud mass and number concentrations in the model.

- The increases in temperature and water vapor in the TTL are primarily contributed by the radiative heating of black-carbon.

Future Work

- Observation: CALIPSO aerosol data are analyzed to identify the vertical distribution of aerosols, especially absorbing aerosols over the South-East Asia, in relation to clouds and water vapor measurements. The Fu-Liou radiative transfer model will be used to quantify aerosol and cloud radiative effects. Compare with OMI data.
- Modeling: A cloud-resolving WRF-Chem simulation with nested domains over Asia is being conducted to distinguish the roles of aerosols, clouds, deep convection and other processes.